Earth Science Applied to Air Quality in Alabama
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I. Abstract

The production of tropospheric ozone under elevated temperatures by interaction with man-made pollution has caused adverse health effects and economic strain for several communities in Alabama. While two counties are in violation of the federal standards for airborne pollution established by the U. S. Environmental Protection Agency, five more are likely to be designated in non-attainment status by the end of 2004. The DEVELOP Air Quality team from the NASA Langley Research Center studied tropospheric ozone levels and particulate matter concentrations from the Jefferson and Mobile counties in Alabama in efforts to aid the policy-makers to best serve the Alabama community. The team organized and analyzed the data to create graphs and find correlations among ozone, particulate matter, temperature, asthma attacks, and wind speed. The correlations will be used to give further information about the "Urban Heat Island" effect and to investigate the validity of pollution travel and its subsequent health effects. The team identified and collected various data products from NASA missions that were fed into pre-existing predictive models.

The team identified data products from NASA missions that were used as inputs into predictive models that show the distribution of air pollutants throughout surrounding communities. One model, SLEUTH, was used to predict expected urban patterns and land use change. Version 4.7 of the HYSPLIT model was also used to demonstrate both forward and backward point trajectories of air parcel movement. This enabled the team to predict the origin and destination of pollution in Alabama. Plume modeling from HYSPLIT 4.7 was used to visually display changes in the concentration of ozone as air parcels moved. The model outputs were combined in a visualization demonstrating air pollution based on developing trends in the region. A program, written in C++, was composed in notepad and run on the data files of particulate matter and ozone to output graphs and correlations between pollutants and temperature.

The final result is a computer visualization that compiles relevant, historical information and research about air quality into a comprehensive format to inform viewers about current air quality issues. The visualization begins with a global view and includes an explanation of the project and its objectives. The visual displays an animation of Alabama and specific cities, the Landsat 7 images of land use change from the 1970's to the present, the thermal data to investigate correlations between heat and pollution, and the correlations of ozone data, particulate matter data, temperature, wind speed, and emergency room visits for asthma attacks. The visual included the applications of the HYSPLIT 4.7 plume models and forward and backward trajectories of ozone on May 30, 2003, a day of particularly high ozone levels, as well as asthma attack statistics. Finally, this information will be returned to the local community and policymakers to enable decisions that best serve the Alabama community.

II. Introduction

The Environmental Protection Agency (EPA) predicted that 243 counties across the United States would be in violation of the federal air quality standards by the end of 2004. While some counties have made strides to reduce airborne pollutants, others delayed the initiation of the long and expensive process of cleaning the air around them. Increased pollutants cause many health problems for a community and the non-attainment designation prohibits new companies from entering the area. Alabama was no exception with two counties designated as non-attainment and several others, such as Mobile County, experienced a steady increase of pollutants (2). Counties in Alabama faced difficulty in complying with the EPA's standards for airborne pollution, especially tropospheric ozone and particulate matter. These pollutants caused adverse effects to the health and economy of local communities.

The EPA first classified Birmingham, Alabama as a non-attainment area in March of 1978 for failing to meet the 1-hour ozone standards (17). The public concern arose in 2001 when officials noticed the county had yet to reach attainment status for more than a month at a time since the first report in 1978. The EPA is in the process of transitioning from the 1-hour standard of 0.12 parts per million (ppm) to a new 8-hour standard with a limit set at 0.08 ppm, making standards of air quality better and safer for communities and making attainment status more difficult to achieve and sustain. Non-attainment status prohibits new companies that could contribute to the pollution from entering the area. The Alabama Environmental Council estimated that Alabama lost 4.6 billion dollars in capital investments throughout the 1990s, as a direct result of non-attainment status.

The EPA has classified Mobile County as a non-attainment area from 1978 to 1986. Since then, the county has had elevated levels of ozone and particulate matter and could be placed back in non-attainment status if preventative measures are not implemented in the near future. Currently, this county has met the national primary or secondary ambient air quality standard (NAAQS) for both particulate matter and ozone. The new 8-hour standard will make attainment status more difficult to maintain in Mobile County. As directed by the EPA, five monitoring stations are being placed throughout Mobile to monitor ozone, particulate matter, and numerous other pollutants. Another important factor is wind direction, especially in Mobile because many companies argued that the air pollutants are blown into the county from surrounding areas in the Gulf of Mexico.

The team was created at the 2002 Southern Growth Policies Board Conference in South Carolina when Alabama delegates approached DEVELOP with concerns of poor air quality. The original study was focused on Jefferson County because it has had problems maintaining acceptable air quality for three decades. The DEVELOP team presented their results at the 2003 conference where a representative from the Mobile County Health Department asked the team to do a similar study in Mobile County. Dr. Bert Eichold, Director of the Mobile County Health Department requested that the Air Quality study be expanded to cover the Mobile Bay Area, and that the focus be on the health effects of the pollutants on the surrounding community. Specifically, Dr. Eichold asked the team to investigate the relationship between elevated levels of pollutants and asthma admissions at local hospitals.

2.1 Six Common Pollutants

There are six common pollutants for which the EPA has set production standards to maintain healthy air quality. The pollutants are ground-level ozone (tropospheric ozone, ground-level ozone, and ozone are all terms for the same pollutant used interchangeably in this report), particulate matter, carbon monoxide, lead, nitrogen oxides, and sulfur dioxide. While all six pollutants affect air quality, the team focused on ozone and particulate matter (25).

2.1.1 Ground-level ozone

Ozone is a gas comprised of three oxygen molecules. In the presence of sunlight and high temperatures, oxygen (O_2) reacts with nitrogen oxides (NOx) and volatile organic compounds (VOCs) to form ground-level ozone (O_3) (23). Unlike stratospheric ozone, which occurs naturally 10 to 30 miles above the earth's surface and shields the Earth from ultraviolet rays, tropospheric ozone is hazardous to humans and many forms of vegetation (18). Emissions from industrial facilities and automobile exhaust are two leading sources of both NOx and VOCs. Many urban areas have higher levels of ozone because of the "Urban Heat Island" effect, which is the idea that cities radiate more of the sun's heat than rural areas, making the surrounding conditions hotter. Since elevated temperature is a contributor to the formation of ozone, pollution levels tend to be higher in urban area. Rural areas suffer from poor air quality as well because of winds carrying pollutants far from their original point sources.

Breathing ozone, even at low levels, triggers a number of health problems including acute respiratory distress and respiratory illnesses such as bronchitis and pneumonia, and aggravates asthma (4). A number of studies over the years have shown an increasing number of health effects associated with ozone. Short-term effects include but are not limited to shortness of breath, chest pain, and eye, throat, and nose irritation (12). Tropospheric ozone may cause permanent lung damage after long-term exposure, and also damages plants and ecosystems (12).

The Clean Air Act, passed by Congress in 1970, requires the EPA to establish air quality standards to protect the health and welfare of communities. The EPA has traditionally focused on local control strategies in areas of the country with high measured levels of ozone in the air to address ground-level ozone pollution. In recent years, the EPA and the states have recognized the need for more aggressive programs to reduce the production of ozone and other pollutants such as NOx that can cause ozone problems hundreds of miles away. In 1997, the EPA revised the air quality standards for ozone to better reflect the studies showing that longer-term exposures to moderate levels of ozone may cause irreversible changes in the lungs (12). The EPA's new standard is currently under legal challenge and updates on this action can be found on the EPA web page at Airlinks. The EPA continues to collect air quality monitoring data from local ground-based stations to identify areas of the country that are routinely unable to meet the existing and new ozone air quality standards (12).

Although many cities have made efforts to control ozone by reducing local emissions, incoming ozone transported by wind needs to be addressed. In 1998, the EPA issued a regulation that will significantly reduce regional emissions of NO_x in twenty-two states and the District of Columbia, and in turn, reduce the regional transport of ozone (18). Some regional strategies for reducing ground-level ozone include:

- Reducing NOx emissions from power plants and combustion sources
- Introducing low-emission cars and trucks
- Using "cleaner" gasoline
- Improving vehicle inspection programs (11)

2.1.2 Particulate Matter

Particulate matter, or PM, is the term used to describe particles in the air such as dirt, dust, smoke, and even liquid droplets. Particles directly emitted into the air usually come from automobiles, factories, construction, and burning of wood. Other particles are not directly emitted into the air, and are formed from reactions between burning fuels and sunlight or water vapor. Such combustion reactions can be found at factories, power plants, and cars. Descriptions of PM are usually classified by size; $PM_{2.5}$ is used for particles, which have diameters less than 2.5 micrometers and PM_{10} is for particles between 2.5 and 10 micrometers in diameter. The smaller particles, $PM_{2.5,}$ pose the greater health risk, as the particles are small enough to penetrate deep into the lungs when inhaled. A high correlation has been established between elevated levels of PM and increased emergency room visits, hospital admissions, and even death (20, 26).

The Alabama Environmental Council estimated that for every dollar spent on power plant clean-up, two to five dollars will be saved in medical costs. Gadsden, a city in Alabama, was rated as the number one city for per capita deaths from PM. With four of the top ten cities for per capita deaths from particulate matter, the state of Alabama had the third highest rate of premature deaths from particulate matter in the country. The state will be required to reduce particulate matter concentrations in the near future once the EPA has designated areas in non-attainment status for particulate matter. For PM emissions, the EPA asked the state governments to recommend counties to be designated as non-attainment and will modify and approve the state's recommendations by the end of 2004 (9).

2.1.3 Carbon Monoxide

Carbon monoxide (CO) is a gas created through partial combustion reactions, or when carbon in fuel is not entirely burned. Colorless and odorless, CO is a component of motor vehicle exhaust, which makes up approximately 56% of all CO emissions across the nation. Other sources of CO in the outside air are non-road engines and vehicles, industrial processes, residential wood burning, and forest fires. Carbon monoxide causes harmful health effects as it reduces oxygen delivery to the body's tissues and organs, affecting the cardiovascular and central nervous systems. Additionally, CO contributes to the formation of smog and ground-level ozone (6).

2.1.4 Lead

Lead, emitted primarily from motor vehicles and industrial sources, is a metal found naturally in the environment and in manufactured products. Urban and industrial areas that burn fuel may have high lead levels in the surrounding air. Infants and young children are especially susceptible to adverse health affects caused by exposure to lead. Lead also accumulates in soil and water and subsequently harms animals and fish (15).

2.1.5 Nitrogen Oxides

Nitrogen oxide is the term used to describe the group of gases composed of nitrogen and oxygen molecules in varying amounts. Highly reactive and typically colorless and odorless, NOx is formed by burning fuel at high temperatures, such as in a combustion process. The sources of NOx are mainly motor vehicles and electric utilities, as well as other industrial, commercial, and residential sources that burn fuels. Nitrogen oxides are unique from the other six common pollutants because they are the only pollutant that has not decreased significantly since the EPA's Clean Air Act of 1970; in fact, NOx emissions are increasing. One of the major concerns of NOx is that it is one of the main components of the formation of ground-level ozone. Another concern is that NOx reacts to form airborne nitrate compounds, which cause respiratory problems (18).

2.1.6 Sulfur Dioxide

Sulfur dioxide, or SO_2, is the term used to describe the family of sulfur oxide gases, which are formed when fuel containing sulfur is burned, when gasoline is extracted from oil, or when metals are extracted from ore. Sources of SO_2 emissions include power-generating and industrial facilities such as petroleum refineries, cement manufacturing, and metal processing facilities, as well as locomotives, large ships, and some non-road diesel equipment. SO_2 also forms sulfate particles in the atmosphere. High levels of SO_2 emitted over a short period can cause respiratory effects and can be harmful for people with asthma (22).

2.2 Future Air Quality Studies

The Aura mission was successfully launched on Thursday, July 15, 2004 and should serve to revolutionize future air quality studies. Aura is the most recent Earth-observing satellite and will provide crucial information concerning air quality both in the troposphere and the stratosphere. To date, mainly ground-based data of ozone levels and particulate matter concentrations has been available. The Tropospheric Emission Spectrometer (TES) instrument will provide researchers with vertical columns of data, allowing more detailed air quality studies.

In 1991, Congress adopted the Intermodal Surface Transportation Efficiency Act (ISTEA), which authorized the Congestion Mitigation and Air Quality Improvement Program. This new program provided $6 billion in funding for surface transportation projects whose goal is to improve exhaust emissions (7).

The EPA and NOAA have established a national Air Quality Forecasting (AQF) Program partnership. This program will assist localities in improving forecasters' ability to predict the onset, severity, and duration of air quality events in their local community. According to NOAA, the AQF is scheduled to provide next day predictions of 1-hour and 8-hour average ozone concentrations for the Northeastern United States by September 2004. The program should expand to cover the entire U.S. by 2009. Within the decade, NOAA and the EPA plan to expand the forecast to include additional pollutants and extend the forecast to two days or beyond (1).

The EPA will decide what counties will be designated as non-attainment status for $PM_{2.5}$ by the end of 2004. In February 2004, all of the states and tribes of the USA were required to recommend counties that should be designated as non-attainment status for $PM_{2.5.}$ On June 28th and 29th, 2004, the EPA replied to the states' and tribes' recommendations, making modifications and confirming the designations. The governments must create plans to meet the EPA's standards within three years once the non-attainment designations become effective at the end of 2004. The plans must reduce "air pollutant emissions contributing to fine particle concentrations" (9).

III. Materials & Methods

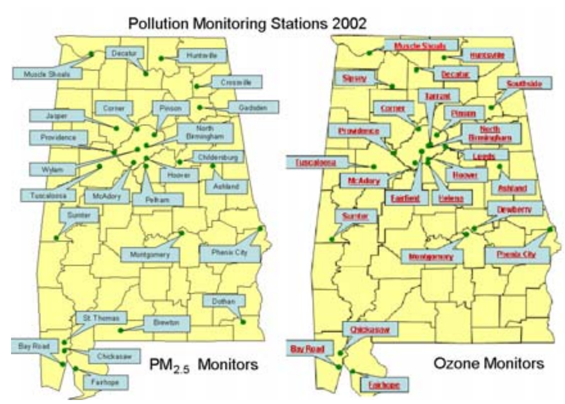
The product to the community included a presentation to the customers at the 2005 Southern Growth Policies Board Conference, a technical paper submitted for publication and available to the community, and a computer visualization to better help the Alabama delegates and policy makers make informative decisions regarding the air quality in Alabama. These products all require both NASA and non-NASA data and information.

The following data sources were instrumental in both the creation of the final visual as well as the general understanding of air pollution for the team. Orthoimagery from the United States Geological Survey (USGS) illustrated land use while providing a detailed picture of Mobile and Jefferson Counties. This enabled the team to better understand the layout of the areas as well as what areas are more industrial and might have higher pollution levels. Images from the Landsat missions 5 and 7 (launched March 1, 1984 and April 15, 1999, respectively) were complied with images obtained from the Aster instrument on the Terra mission to show the land cover of Alabama. Other non-NASA data was gathered from many organizations including the National Weather Service (NWS) and the United States Census Bureau.

Researchers gathered elevation data from the Shuttle Radar Topography Mission (SRTM) to layer with thermal data obtained from the Moderate Resolution Imaging Spectroradiometer instrument (MODIS) located on both the Aqua and Terra missions. The temperature data was compared to that obtained from the ground-based NWS temperature data to determine the most accurate temperature for desired times. Together, these images show how temperature varies across Alabama.

3.1 Correlations

Data was gathered from several monitoring sources in Alabama for the purpose of identifying significant correlations that might further contribute to the understanding of pollution formation and its health effects. The 1-hour measurements of ozone and particulate matter of diameter less than 2.5 micrometers were taken from the EPA's ground monitors in both Mobile and Birmingham (19, 23). A C++ program, written in text editor, sorted the data by date and hour, and daily maximum values were found using Microsoft Excel. A separate file was created for all maximum values. Other data gathered were temperature, wind speed and "2 min" wind direction from the National Weather Service Forecast Office (13, 16). Students in Alabama gathered data on emergency room visits for asthma attacks for several months in Mobile, Alabama, and the data from January and July 2003 was used.



Initially, the data was organized month by month of the daily maximum levels of ozone, temperature, and PM as well as the average wind speed. Dr. Dale Quattrochi suggested data reorganization so that all five months were accumulated into one data set including May through September. This organization illustrated the progression of the data over the summer months and actually gave significantly different correlations for all relationships than did the previous, separate organization. The organization of the data with respect to time is important. Dr. Eichold added that asthma attacks are actually more prevalent during the winter months rather than the summer months because of the colder air; subsequently, the January 2003 data of Mobile was analyzed. The students on our team also had the asthma attacks statistics for January and July in 2000, but there was no corresponding ozone data from the monitors for Mobile.

The data sets were then correlated using the 'correl' function in Microsoft Excel. The 'correl' function returns the correlation coefficient between two arrays or cell ranges of data. "The correlation coefficient is a quantity that gives the quality of a least squares fitting to the original data," which determines the correlation between two properties (24). The correlation coefficient can be squared to give "a rough percentage for the amount of variation in the final result which is directly attributable to the other variable" (5).

3.2 SLEUTH

The USGS's SLEUTH (Slope, Land cover, Exclusions, Urban areas, Transportation, Hydrologic) model used current and historic information about an area to predict possible future urban patterns and development. While the model was run on the Washington D.C. and Baltimore areas, there is currently no record of a successful prediction of Alabama. In order to apply this model to the Alabama community, the team gathered and converted data into the format required by the model.

Input data required by the SLEUTH model include five types of grayscale gif images. All five square images require a consistent number of rows and columns. Road data from two or more time periods and urban data from four or more time periods was needed for statistical calibration within the model (21).

Land use data on clear days was obtained from Landsat missions 5 and 7 and imported into ERDAS 8.7. Images obtained were modified using supervised classification into the following four categories: urban, suburban, water, and land. Each category was assigned its own distinct color and inputted as the actual land use image. The classified images were re-projected, and then Mobile and Birmingham were separated as areas of interest. These subset images will then be put into the SLEUTH model and used to predict possible future urbanization.

3.3 HYSPLIT

The HYSPLIT 4.7 model is designed to compute a broad range of equivocations related to the transport, dispersion, and deposition of specified pollutants. The applications of the model range from routine air quality assessments, especially those in association with emissions of pollutants, to the need to respond to atmospheric emergencies such as accidental radiological releases. Computational outputs vary from simple trajectory to more intricate air concentration patterns.

The HYSPLIT 4.7 model has two basic forms of output available: air concentrations and trajectories. The model performs calculations by using a cross between Lagrangian and Eulerian methods (10). The transport and dispersion of hazardous chemicals are calculated by assuming a single puff dispersion with a Gaussian horizontal distribution or from the dispersion of an initial fixed number of parcels. Diffusion and advection calculations are executed in a Lagrangian framework, in which a fixed initial amount of parcels are transported about the model domain by the average wind field. Air concentration calculations are executed on a fixed grid at a specific grid point, which is defined by latitude and longitude intersections. A single released puff expands until its size exceeds that of the meteorological grid cell and then the puff splits into several new puffs, each having its own share of the hazardous chemical mass. By default, the model assumes particle dispersion in the vertical directions and puff distribution in the horizontal direction and combines the two (14). Therefore, the more accurate vertical dispersion parameterization of the particle model is combined with the advantage of having an expanding number of puffs to represent the hazardous chemical distribution as the pollutant's coverage area increases.

Overall, Lagrangian models are well equipped for rapid calculations for pollutant point source and well suited to model approaches ideal for situation where quick renovations are important. The performance of the model has also been evaluated qualitatively by comparing the calculations for various applications to real data observations (i.e. balloon trajectories, measured air concentrations of inert tracers). Assessment studies with the model have also been conducted for ozone concentrations.

The NOAA HYSPLIT 4.7 model was selected by the Summer 2004 because of its ability to calculate both forward and backward trajectories with plume modeling. The backward plume model was used to determine the concentration of pollutants in air entering the area. The forward plume model was then run for the same days and showed where polluted air traveled once it left the city of Mobile. According to the help section of the HYSPLIT program, the inputs included the following: the starting location in latitude and longitude coordinates; under the pollutant section, the emission rate (1 hour), hours of emission, and the release date; under the concentration section, the center of latitude and longitude, the spacing and span in degrees of the latitude and longitude, the height of the levels (M Agl), the sampling start and sampling stop times, and the sampling interval; and under the deposition section, the particle diameter (micrometers), density (g/cc), shape, deposition velocity (m/s), pollutant molecular weight (g/mole), A-ratio (surface reactivity ratio), D-ratio (Diffusivity ratio), Effective Henry's constant, Actual Henry's constant (M/a), In-cloud removal (1/s), Below-cloud removal (1/s), radioactive decay half-life, and pollutant re-suspension factor (1/m).

IV. Results & Discussion

4.1 Correlations

A moderate correlation between $PM_{2.5}$ and ozone, 0.391607, was found for the May through September 2003 data in Mobile (Table 6.1). This seems reasonable and is the best correlation in all of the tables. The negative correlation between ozone and average wind speed, -0.33347, seems logical as well. However, the small negative correlations between $PM_{2.5}$ maxima and asthma attacks, -0.24325, and the ozone maxima and asthma attacks, -0.19499, were initially surprising and counter-intuitive, since a significant correlation was expected (Table 6.2).

However, according to noattacks.org, "asthma attacks can occur the same day, but may also occur the day AFTER outdoor pollution levels are high" (5). The asthma attack data was then offset by one day and correlated to the ozone and $PM_{2.5}$ (Table 6.4). The correlation between ozone maxima and asthma attacks offset by one day is 0.336619, which was closer to the expected correlation between ozone and asthma attacks. Dr. William Crosson said that the small negative correlation between ozone maxima and asthma attacks on the same day is similar to what others have found, and that the better correlation due to the offset of one day may include several factors, such as "latency in the body, delays in going to the ER or doctor's office, or the way the ER and doctor visits are time-identified." Though any of these reasons may relate to the better correlation, it is unknown whether this correlation is significant or not (8).

The daily maxima of $PM_{2.5}$, ozone, and temperature versus time in days for May 2003 through September 2003 were graphed, as well as the daily average wind speed and "2 min" wind direction, and the number of emergency room visits for asthma attacks per day in Mobile for July 2003 (Table 6.3, Figures 1-5). The asthma attack data and the temperature and wind speed data were analyzed and graphed for January 2003.

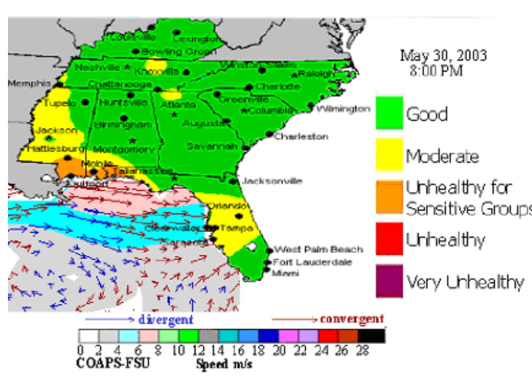
4.2 HYSPLIT 4.7 for the Maximum Ozone levels for May 30, 2003

The tropospheric ozone plume modeling for the visualization was based on May 30, 2003 at 7 am for both a forward and backward trajectory as described previously. The ozone levels for monitors #0003 and #2005 at 7 am were 0.035 ppm and 0.049 ppm, respectively. After analysis of the EPA's monitor data for ozone levels on May 30, 2003, the maximum was found to be at 6pm on monitor #0003 of 0.089 ppm and at 4pm on monitor #2005 of 0.109 parts per million (ppm). The HYSPLIT plume model may reveal further information if it was centered at the time of maximum ozone levels. The time of 4pm or 2100 UTC was chosen for an alternative run of the HYSPLIT program. Since monitor #0003 had a level of 0.085 at 4pm and monitor #2005 had a level of 0.095 at 6pm, the 4pm starting time was chosen. The center of the coordinates for the HYSPLIT model was 30.47644… degrees latitude and –88.141090… degrees longitude, which are the exact coordinates of the #2005 monitor to the sixth decimal place. The bar charts in Table 6.6 and 6.7 show the ozone levels of both monitors for May 30, 2003, and Tables 6.8-6.14 show the backward trajectory of the plume model of ozone, starting at 4pm on May 29, 2003, going back by four-hour increments. Tables 6.8, 6.15-6.17 show the forward trajectory of the ozone plume model starting at 4pm on May 30, 2003 and going forward in four-hour increments. These models were created to give a better idea visually of where the air pollution may have originated from and where it is destined.

4.3 Visualization

One of the team's products for the community was a visual that demonstrated how geographic location in addition to wind speed and direction can play a role in both the concentration and location of airborne pollutants. The visual is a vital tool that enables the team to effectively display the gathered information to the Alabama communities.

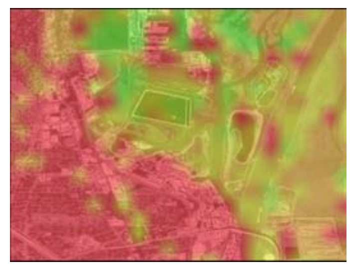
The visual begins with EPA ozone contour data layered with wind speed and direction from the QuikSCAT mission. Both data sources were gathered for May 30, 2003 due to the high level of ozone concentration experienced that day. The data was compiled together to show how the concentration increases once polluted air parcels

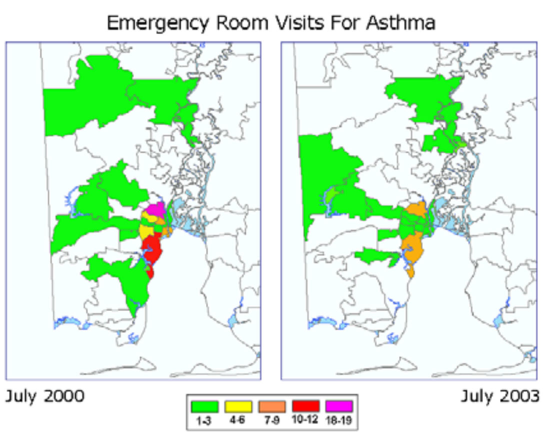


enter the Mobile Bay Region around 4:00 PM. The wind direction also shows how the geographic location of the Gulf of Mexico can contribute to polluted air being re-circulated throughout the area.

The animation continues with NOAA HYSPLIT model outputs layered on top of Landsat 7 imagery. The model outputs are transparent, showing the land cover underneath. As the animation begins, the backward plume model shows the concentration of ozone changing as the air parcels enter the Mobile Bay Region. The animation continues with the forward plume model, showing where the pollution travels once it leaves the city of Mobile. Information from this model can be powerful in the hands of policy-makers as it allows them to more accurately determine the amount of pollutants generated from urban areas.

Urbanization has been linked to increased levels of airborne pollution. To address this, the visualization tries to explain the Urban Heat Islands effect. Images from Landsat missions were classified using ERDAS software and coupled with heat signatures created by layering thermal data on top of orthoimagery. The thermal data is transparent, with higher temperatures in red and orange, and lower temperatures in green and yellow. Through the visual, one can clearly see the industrial and urban areas are red while rivers and farms are green and yellow. This shows that the cities radiate more heat, yielding a higher temperature there then in surrounding rural areas.





In order for the visual to display the health effects of pollutants on the communities, the number of emergency room visits pertaining to asthma attacks were organized according to zip codes. This enables a visual representation of the health effects and can be seen on the left. A decrease in asthma attacks has occurred over the tree years as indicated by the key.

V. Acknowledgements

We would like to thank the following people: Mike Ruiz for his help and belief in students; Janice Cawthorn, Dr. Norman Loney, and Thomas Spencer for their guidance and assistance with our project; Dr. Dale Quattrochi of NASA Marshall Space Flight Center and Dr. Bert Eichold director of the Mobile County Health Department for being our enthusiastic science advisors; our two team members in Alabama, Andy Hilburn and Rebecca Alsip for their instrumental help in gathering data this summer; the DEVELOP team for their help and support.

Appendix

Table 6.1 May through September 2003, Mobile, Alabama

	PM2.5 maxima	Ozone maxima	Temperature maxima	Average Wind Speed
PM 2.5 maxima	1.0	0.391607	0.082902	-.19097
Ozone maxima	0.391607	1.0	0.206988	-0.33347
Temperature maxima	0.082902	0.206988	1.0	-0.30296
Average Wind Speed	-0.19097	-0.33347	-0.30296	1.0

Table 6.2 July 2003, Mobile, Alabama

	PM2.5 maxima	Ozone maxima	Asthma Attacks	Average Wind Speed
PM 2.5 maxima	1.0		-0.24325	
Ozone maxima		1.0	-0.19499	
Asthma Attacks	-0.24325	-0.19499	1.0	0.141881
Average Wind Speed			0.141881	1.0

Table 6.3 January, 2003, Mobile, Alabama

	Temperature minima	Asthma Attacks	Average Wind Speed
Temperature minima	1.0	0.151686	
Asthma Attacks	0.151686	1.0	0.202087
Average Wind Speed	0.202087		1.0

Table 6.4 July 2003, Asthma Attacks offset by one day

	PM2.5 maxima	Ozone maxima	Asthma Attacks
PM2.5 maxima	1.0		0.023457
Ozone maxima		1.0	0.336619
Asthma Attacks	0.023457	0.336619	1.0

Figure 6.1

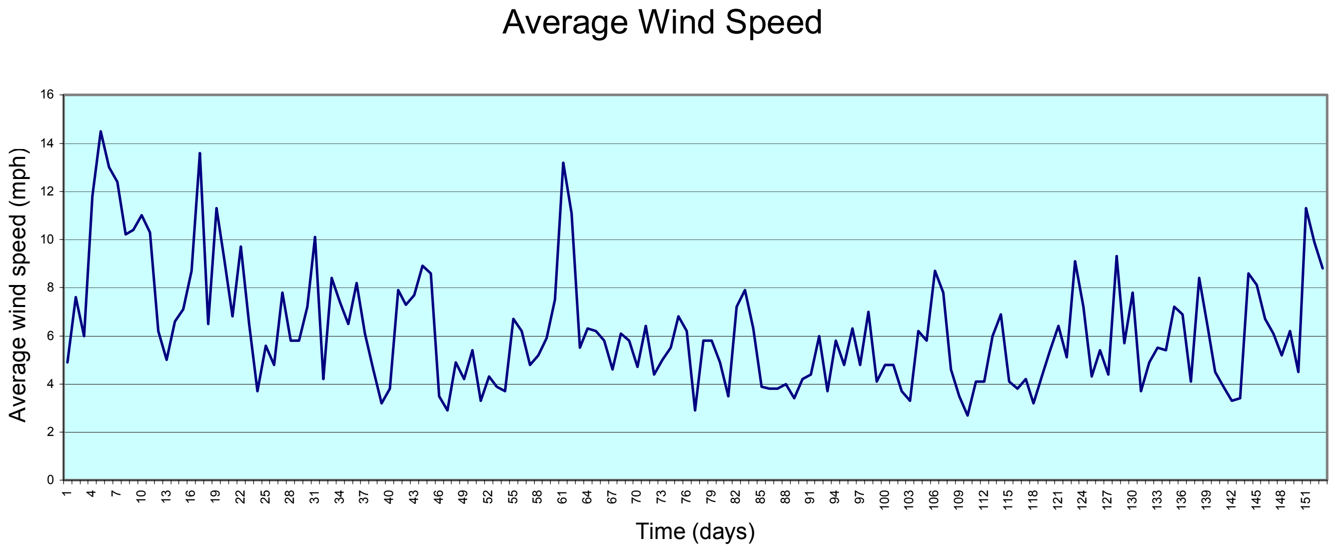


Figure 6.2

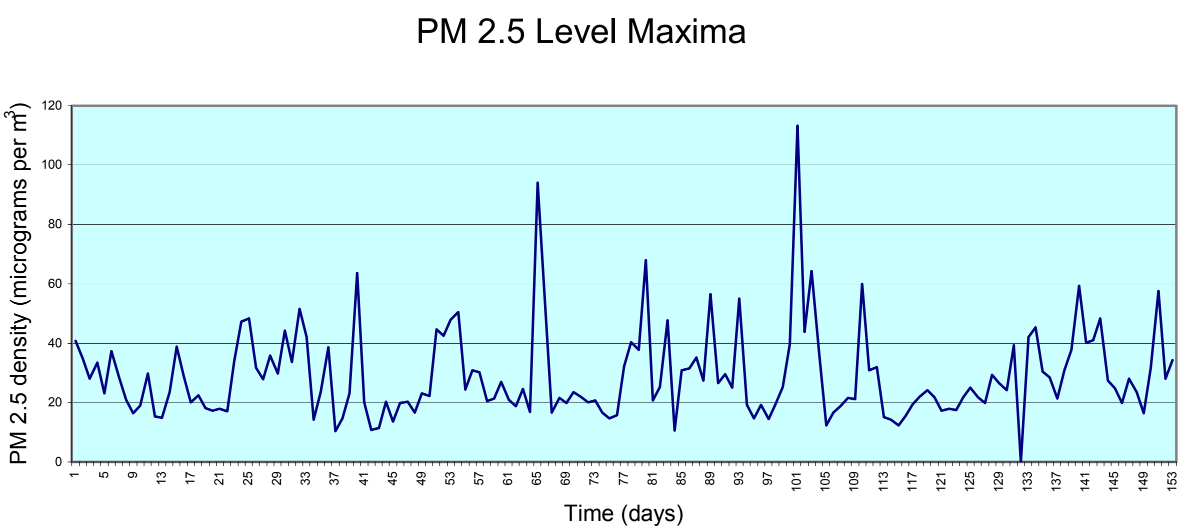


Figure 6.3

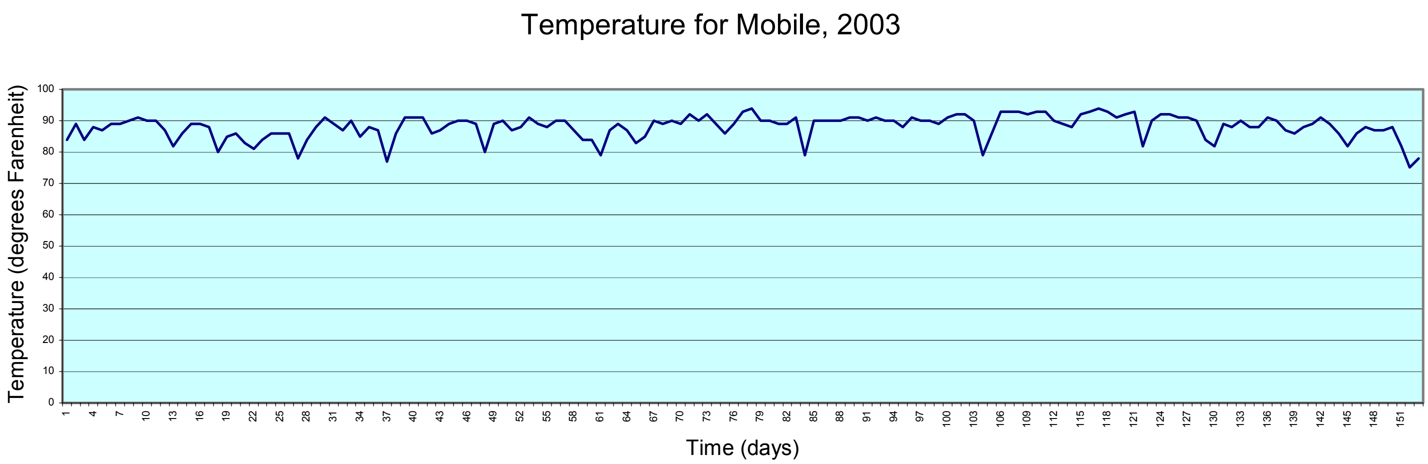
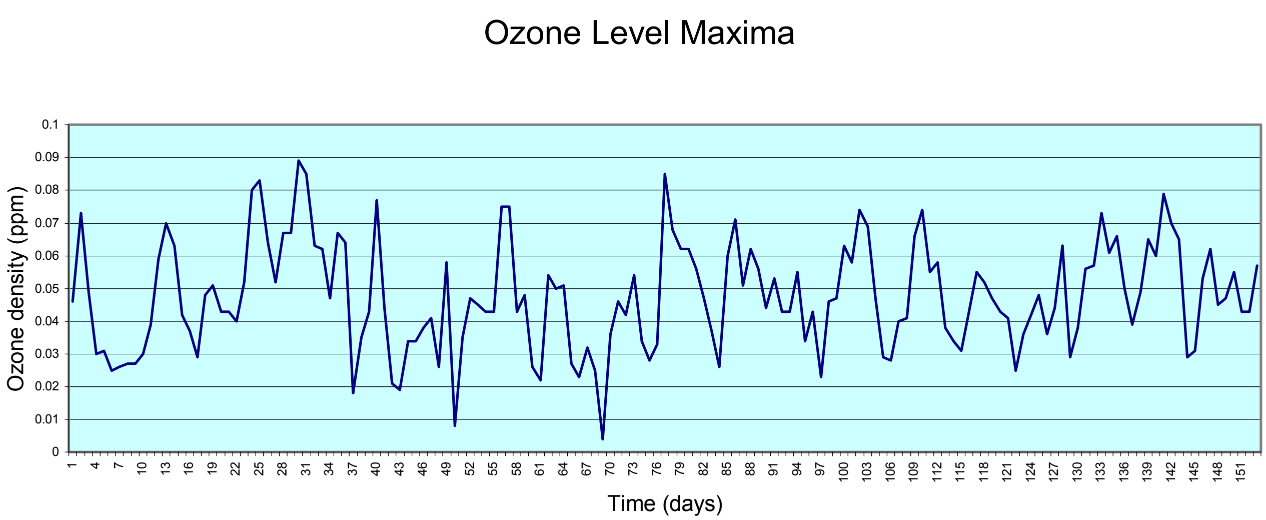


Figure 6.4



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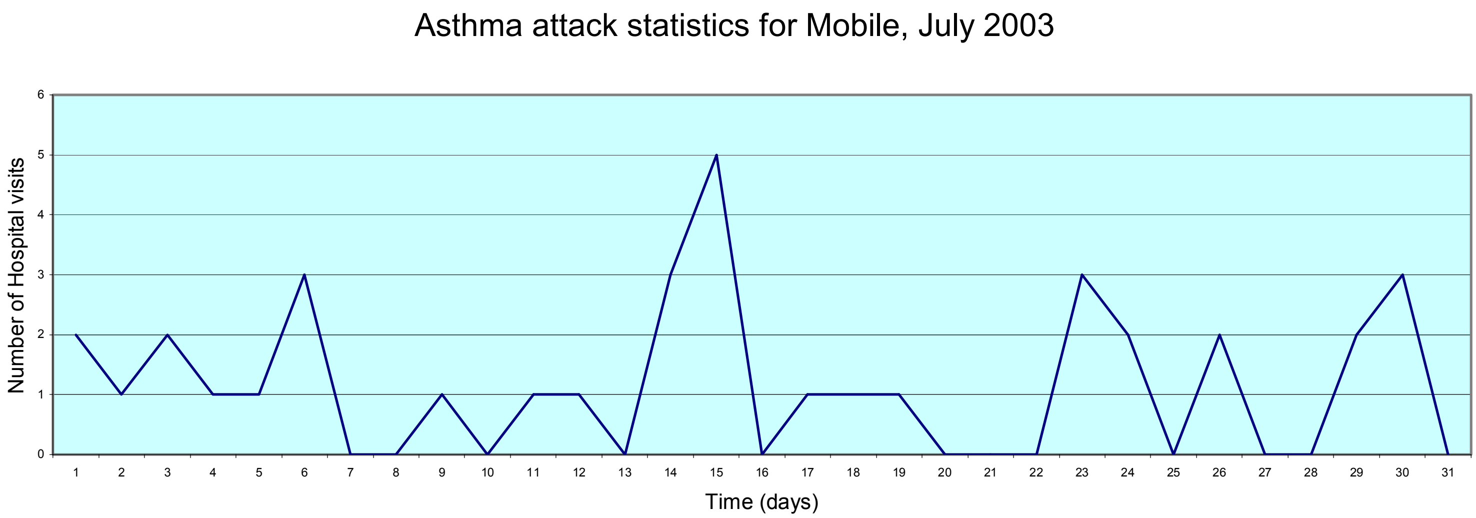


Asthma attack statistics for Mobile, July 2003
Number of Hospital visits
0
1
2
3
4
5
6
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Time (days)

Figure 6.6

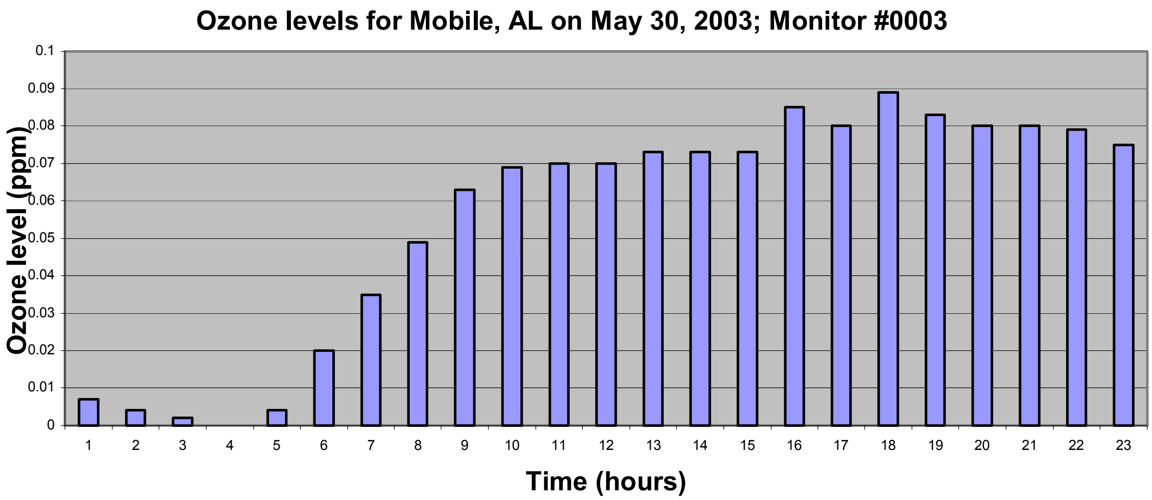


Figure 6.7

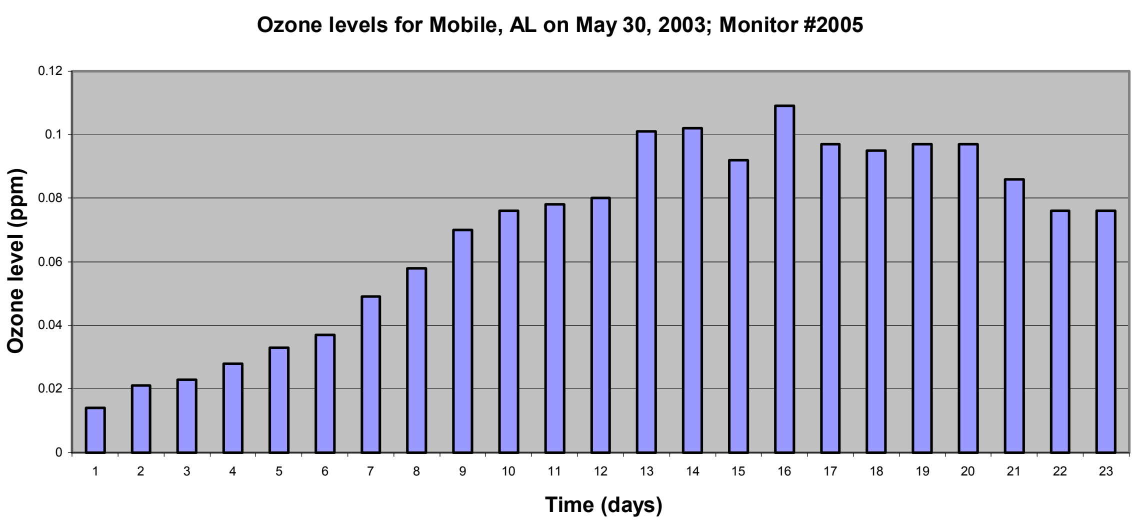


Figure 6.8

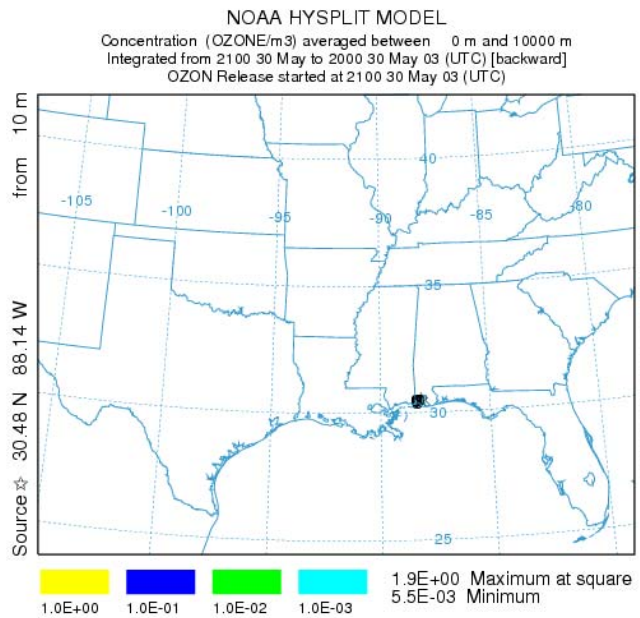


Figure 6.9

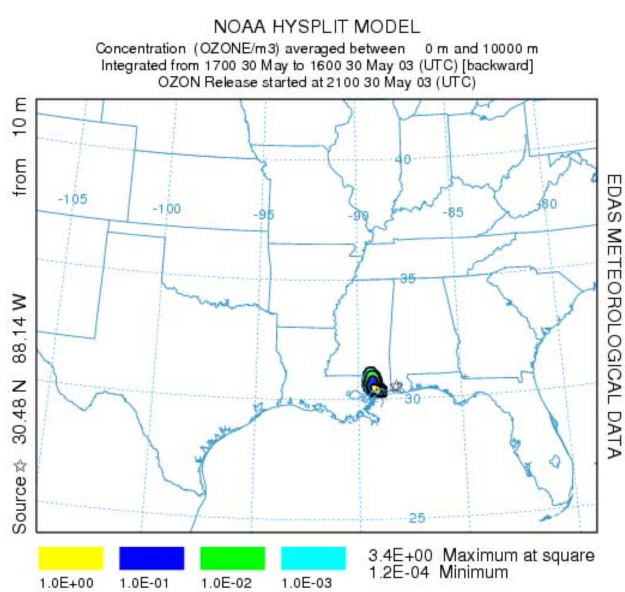


Figure 6.10

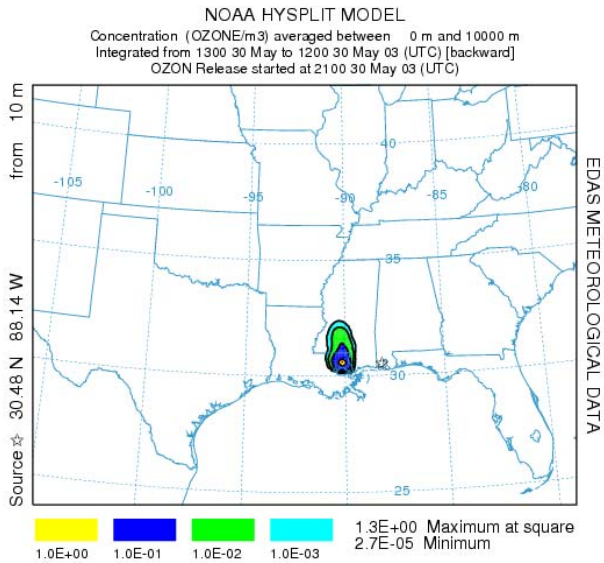


Figure 6.11

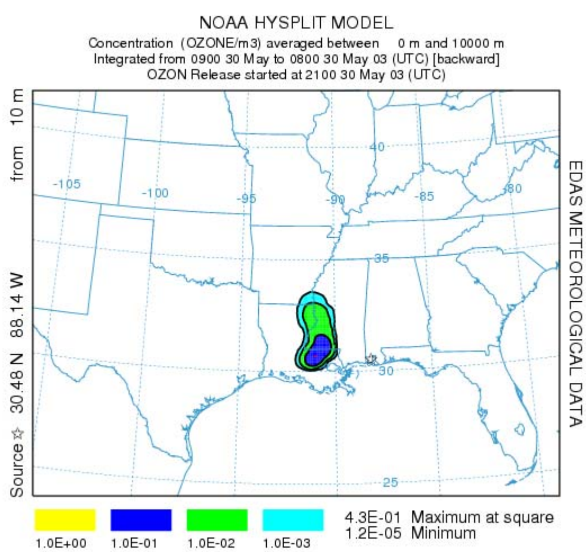


Figure 6.12

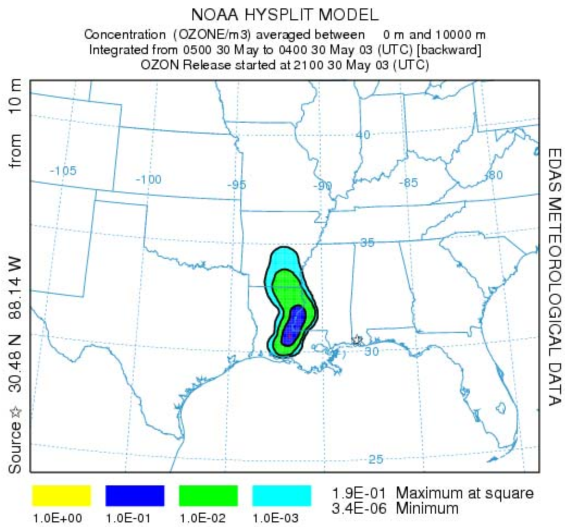


Figure 6.13

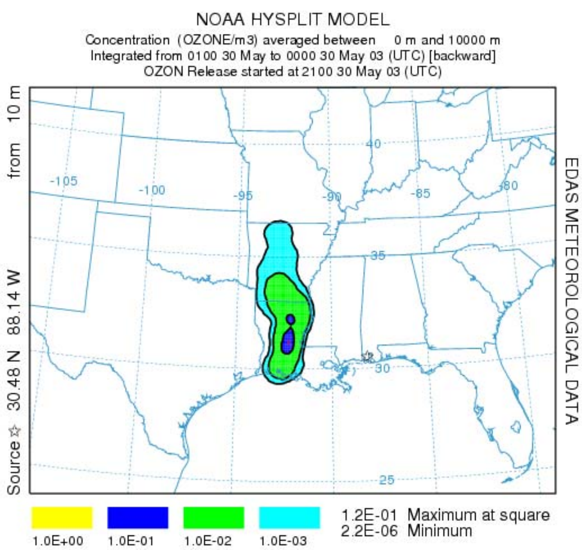
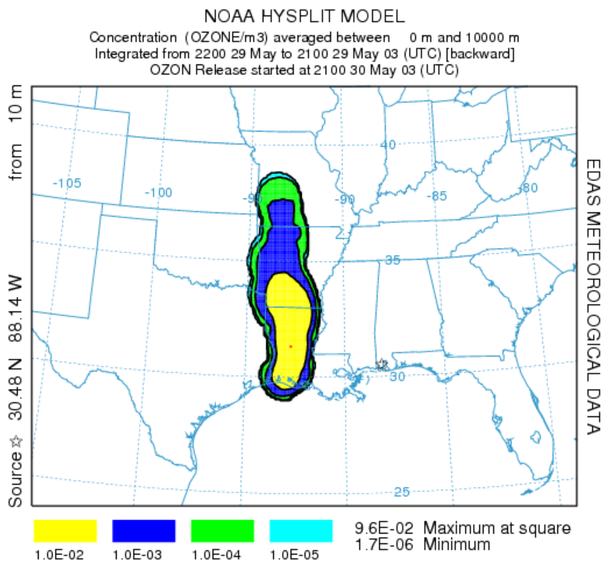


Figure 6.14



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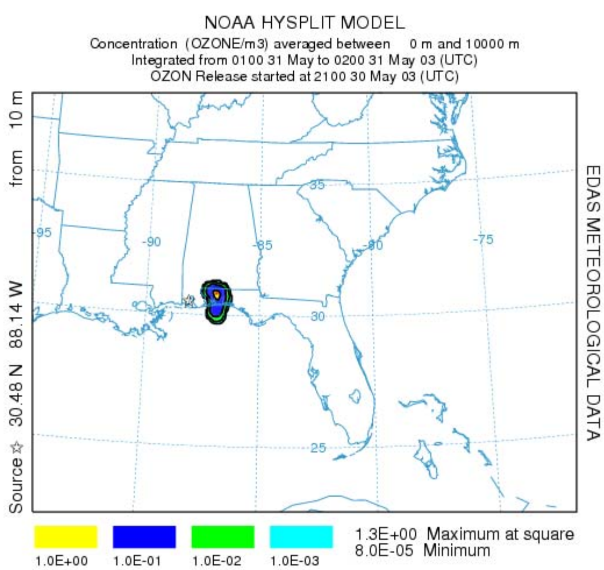


Figure 6.16

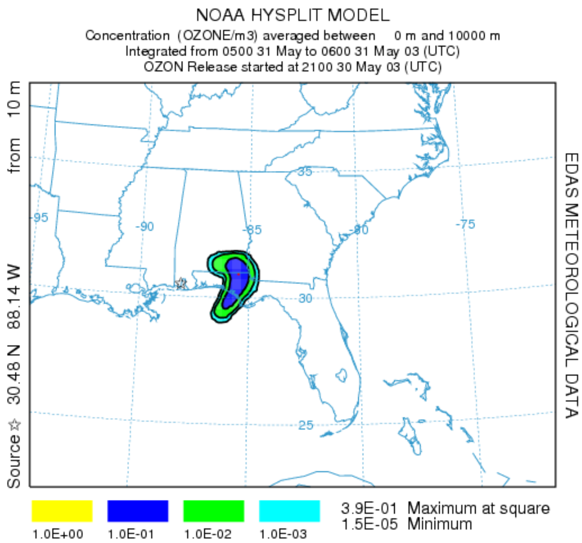
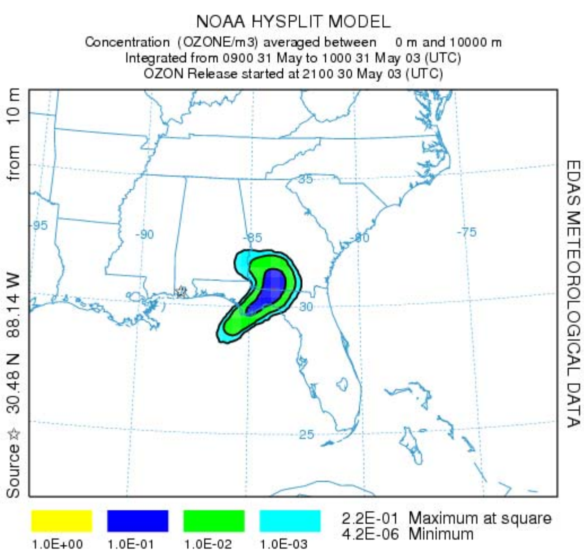


Figure 6.17



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